PREDICTING AND PROGNOSIS OF MICRO MACRO AND CALCIFICATION OF MAMMOGRAM IMAGES USING MACHINE LEARNING TECHNIQUE

A SYNOPSIS

Submitted by

GUL SHAIRA BANU JAHANGEER
(Reg. No. 201807262)

in partial fulfillment for the award of the degree

of

DOCTOR OF PHILOSOPHY

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

SCHOOL OF COMPUTING

KALASALINGAM ACADEMY OF RESEARCH AND EDUCATION

(DEEMED TO BE UNIVERSITY)

ANAND NAGAR, KRISHNANKOIL – 626126

TAMILNADU, INDIA

JULY 2022

1. INTRODUCTION

Cancer is a serious growth that is not a communicable disease, but rather a collection of more than a hundred issues that cause a collection of cells to become strange and isolate without control, attacking different tissues. These cells can spread throughout the body via the bloodstream or lymphatic system. The body is made up of various types of cells that are essential units of life, and these cells develop and isolate in a controlled manner to maintain the body's health. When cells become old or damaged, they die and are replaced by new cells in a different way, this cycle is known as apoptosis. However, in some cases, this personalized cycle fails miserably. A cell's hereditary material (DNA) directs normal cell development and division. If DNA is harmed or changed, causing transformations, cells cannot be destroyed and cells continue separating when the body doesn't need them, these extra cells structure a mass of tissue known as a tumor [1, 2].

These tumors have different types like one is a considerate tumor and another is a dangerous tumor. Considerate tumors are not carcinogenic, they don't spread to different pieces of the body yet dangerous tumors are malignant, cells in these tumors can spread to different pieces of the body (metastasis). Most of the cancer impacts are not brought about by the immediate result of an indispensable organ by an infringing dangerous tumor. It is just because of contamination by microscopic organisms, infections, and growths, microorganisms that typically would be demolished by the invulnerable framework. The harmful body is typically seriously resistant due to fundamental by the malignant growth measure and mostly as a result of the negative, poisonous impacts of ordinary therapy, chemotherapy, medical procedure, and radiation. Serious condition of health or gauntness may influence up to 90% accounting by entire development disease patients and record for half of all malignant growth passings [3]. It can adequately go through the entire human body's power consumes and it may leave in terms of the desperate condition of cell functions known as cachexia. Recollect the cells are in the favor of glucose as the main resource of energy rather than oxygen. Hence,

the protein-calorie lack of healthy sustenance is regularly connected with weak youngsters in developing countries. It isn't phenomenal among hospitalized in-patients, by and large, prompting generally shortcoming, indifference, increments in mortality and diminished insusceptibility, and helpless treatment reaction [4].

A transformation found in master quality causes strange chromosome replication, causing entire areas of chromosomes to be missing or copied. This causes a change in quality measurements, causing cells to produce almost nothing or an excessively explicit protein. These chromosomal abnormalities influence the measure of at least one protein is used to control the different cycle cells, for example, development elements or tumor silencers, the outcome might be malignant growth. It has solid proof that the exorbitant expansion of methyl gatherings to qualities associated with this cycle, fixing DNA, and apoptosis may be normal for certain malignant growths. There might be various components prompting the advancement of malignancy. It may confuse the complicated assignment of figuring out the root cause of disease [5, 6].

2. LITERATURE SURVEY

Cancer is the most dreadful disease, and it is a grouping of related diseases. In each type of cancer, some of the body's cells begin to separate uncontrollably and multiply in the surrounding tissues. Cancer is classified as a diverse disease. Early cancer detection and prevention are required to support subsequent clinical supervision of patients. The identification of protein sequences and structural motifs aids in the early detection of cancer. Cancer detection is based on molecular level analysis, and various cancer types require a methodical, exact, and objective diagnosis. In the human body, various types of cancer develop. Breast cancer is one of these types that causes serious health concerns.

Women are more susceptible to breast cancer due to the anatomy of their bodies. Breast cancer can be caused by a number of factors, including age, family

history, breast density, obesity, and alcohol consumption. Depending on the condition of the disease and the quality of the images, various detection and classification approaches are used to detect cancer from breast images from various perspectives. But, still exists a false alarming rate of inaccurate breast cancer detection. This also leads to overtreatment by an inaccurate diagnosis of cancer and under treatment because of unidentified cancerous masses. Therefore, a number of research papers are analyzed and examined for early detection of breast cancer.

Breast cancer is the significant cancer in the worldwide amongst women in order that every eight women have been suffered due this disease throughout their lifetime. Mammography is the one of the most efficient imaging modality to detect breast cancer earlier. Various computer- aided detection algorithms had been widened to assist radiologists for precise diagnosis.

Acharya et al. [7] discussed the exploitation of higher order spectral features mined from thermograms to categorize normal and abnormal thermograms. The higher-order spectral features were extracted and provided to FFANN classifier and SVM. SVM provides high sensitivity and specificity. Saha et al. [8] described a supervised model for recognizing mitosis signature from breast histopathology Whole Sliding Images (WSI). A deep learning framework was designed with handcrafted features acquired from preceding medical challenges were used. The deep learning framework was comprised. Handcrafted features were composed of morphological, textural and intensity features. Precision was enhanced in the recognition and assessment of the breast cancer stage.

Kooi, et al. [9] described CNN for the system for ultimately interprets mammograms. The system was trained on a huge data set of images and CNN performed in terms of sensitivity. The exploitation of position, patient information and commonly exploited manual features in balancing the network were analyzed.

Then the enhancements at high specificity with location and context features were examined. Later an analysis of network was performed to certify screening radiologists on a patch level and the difference among network and readers were considered. On the other hand, discrimination of lesions was not performed to achieve efficient cancer detection.

Radovic et al. [10] proposed the CAD system to detect normal and abnormal breast pattern. The presented method has four major steps: the image preprocessing, the feature extraction, the feature selection and the classification process to classify mammogram as normal and abnormal pattern. Seven classifiers were employed to contrast the effects. Normal breast images and breast image with masses were employed as input images obtained from the mini- MIAS database. Albert et al. [11] analyzed a novel classification paradigm to detect mammogram breast abnormalities through Particle Swarm Optimized Wavelet Neural Network (PSOWNN). This technique had exploited to actual 216 clinical database of mammogram regions obtained from mammogram screening centers. The CAD systems detection performance had been investigated by means of Receiver Operating Characteristic (ROC) curve.

El-Dahshan et al. [12] introduced a hybrid intelligent machine learning CAD system technique to detect automatically brain tumor via MRIs. The experiments were conducted on 101 images with 14 normal and 87 obtained from an actual human brain MRI dataset. The classification precision on training and test images had been 99% that had been considerably better. Furthermore, this method proved its efficiency once compared over some other machine learning newly published methods. The consequences proved this hybrid concept was precise, fast and robust. Parascandolo et al. [13] enhanced the quality and physicians productivity effort by means of increasing the precision and radiological diagnosis consistency. CAD considered mutual physicians and computers roles in which the automated computer analysis was based on just

computer algorithms. Actually, CAD systems were employed to assist earlier diagnostic method and follow-up. Such task had been particularly essential in musculoskeletal diseases, chronic pathologies that required in earlier analysis, enough follow-up, and timely disease indicator observing.

3. RESEARCH PROBLEM

Breast cancer is the frequently diagnosed cancer, other than skin cancer, amongst females in U.S. It is also forecasted that the breast cancer can be the foremost cause of casualties during forthcoming decades. Various studies have demonstrated that early detection and proper treatment of breast cancer may diminish the mortality rate. Mammography cannot stop or decrease breast cancer but are supportive only in detecting the breast cancer at early stages to increase the survival rate. Regular screening can be a successful strategy to identify the early symptoms of breast cancer in mammographic images.

4. RESEARCH OBJECTIVES

The objectives of the research work are:

- To propose algorithms to segment the various cysts, tumors, mass, and calcification in mammogram images and get better segmentation results.
- To optimize and improve the performance of training algorithm accomplish the superlative feature selection process and considering all achievable extracted features to feed input to the classifier.
- To process an algorithm that could enhance the training efficiency of the classifier to detect breast cancer disease in mammogram images.
- To compare and design various machine learning technique for better accuracy in predicting the various cyst, tumors, mass, calcification and breast cancer disease in mammogram images.

- Selecting and comparing support system using computational resource like CPU-based, GPU-based, and cloud-based in order to segmentation and classification.

5. RESEARCH METHODOLOGY

5.1 Early Detection of Breast Cancer using Hybrid of Series Network and VGG-16

Despite many significant achievements in the research of cancer biology and treatment options, breast cancer demonstrates a high incidence and mortality rate among women. Therefore, an accurate early diagnosis of breast cancer is very important. Timely and early detection of breast cancer is the major diagnostic aim. Breast cancer screening among healthy women without palpable breast masses is employed as a secondary preventive method. Screening involves medical examinations, particularly ultrasound examination of the breast, aimed at identifying women with a high probability of developing breast cancer. The prime objective of screening is to identify the disease at an early stage so that the patients can be provided with better treatment options. Screening involves differential diagnosis which helps to effectively choose further investigation procedures, treatment options, and improve the life expectancy.

5.1.1 Proposed Work

To diagnose and detect breast cancer problems in women can be identified using the proposed system by processing mammogram-images. Some examples of image processing methods include feature extraction, classification, segmentation, and filtering. Figure 1 shows the proposed framework.

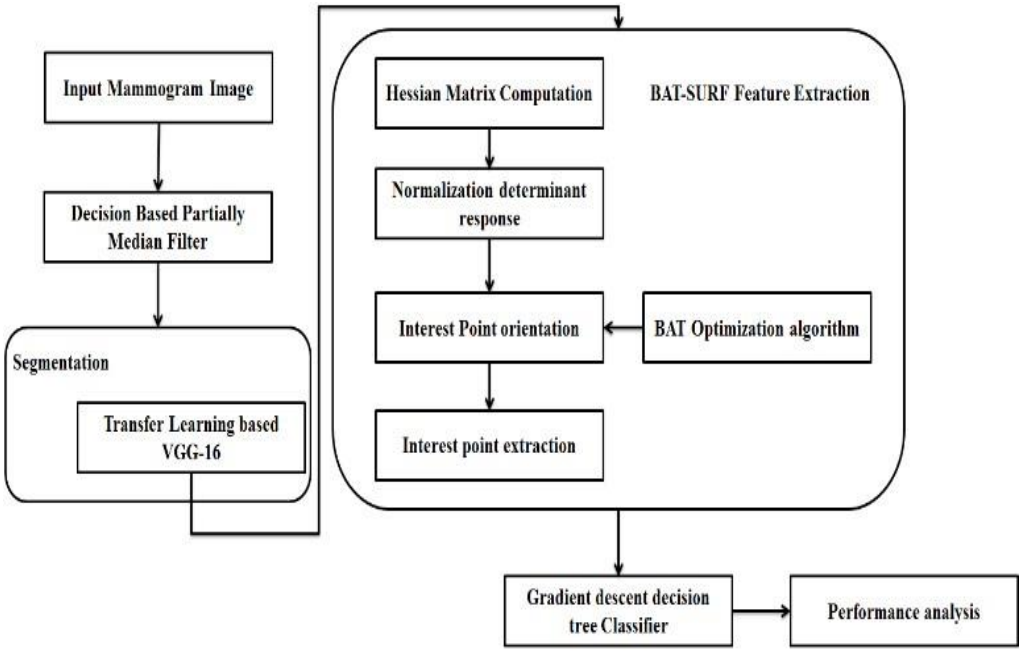

Figure 1: Overall Flow of Proposed Work

Breast cancer diagnosis based on mammogram-images which is reordered by the mammogram in the form of imaging method is known as Mammogram-method. The detection system of breast cancer is indulged with the recorded mammogram-images. Pepper and salt noise is a one type of noising which affects the image which is obtained from the mammogram. Pixels present in the input image can be appeared as white and black and is known to be one type of noise. It is also known as impulse or gaussian noise. As a result, unexpected and pointed disturbances in the image-signal due to these noises. Novel decision based partially-median filter can be used by removing the input image from the result of pepper and salt noise. Following phase is included in the segmentation of filter image. Segmentation is processed in noise-free images into various fragments during the segmentation process to implement for any cancer regions which is present in the mammogram image.

New transfer learning technique is used to carry out segmentation process which is based on proposed VGG-16 process and it is one type of deep learning

model. When compared to machine learning, deep learning is most advanced which works on the principle of artificial intelligence based on unsupervised data. By layers updation, the network is trained correctly by the proposed architecture of VGG-16 and it is providing ground truth of the regions of cancer images that segmented over can be identified. The features dimensions can be reduced when using the VGG-16 technique present in Convolutional Neural Network (CNN) and also time limit is reduced during the integration.

Furthermore, feature extraction can be done by processing the segmented images. Features can be extracted using Speeded Up Robust Features (SURF) from the images of segmentation that optimized with the interest points orientation. Bat optimization technique is proposed to optimize the interest points in conjunction with feature extraction using SURF. Finally, classification of mammogram images for magnitude forecasting is done after extracting the interest points for the breast cancer patient. Gradient descent decision-tree classifier is proposed to classify the extracted images of mammogram which works on the concept of decision tree algorithm.

5.2 Detecting Breast Cancer using Novel Mask R-CNN Techniques

Rather than men, women's usually has high probability of getting affected by the breast cancer. More often, it only occurs in women. Few symptoms can be used to identify breast cancer in women such as any alterations, swelling in breast, blood from the nipple, and breast shape or texture. The treatment is relied only for the cancer stages. Therefore, at initial stage the cancer detection is very much hard and the probability of checking the symptoms is less for this particular disease. Death rate can be reduced by detecting the cancer initially. Therefore, this study is presented to detect the breast cancer using different deep learning methods. Mammogram images are preprocessed which is considered to be an important role that used for the identification of architectural falsification, masses, and micro-calcification.

5.2.1 Proposed Method

Breast cancer prediction is processed by combining the dataset using the proposed method from the mammogram images. Pepper, impulsive-noise, speckle noise, and salt noise is removed using median filter based enhanced fuzzy in which input is initiated in order to increase the image clarity. Segmentation is conducted using mask R-CNN in which the noise free images were given as input for the classifier for predicting the mammogram-images. Efficiency of the proposed system is analyzed based on various performance metrics such precision, recall, accuracy, and F-measure. Figure 2 shows the overall framework for proposed system.

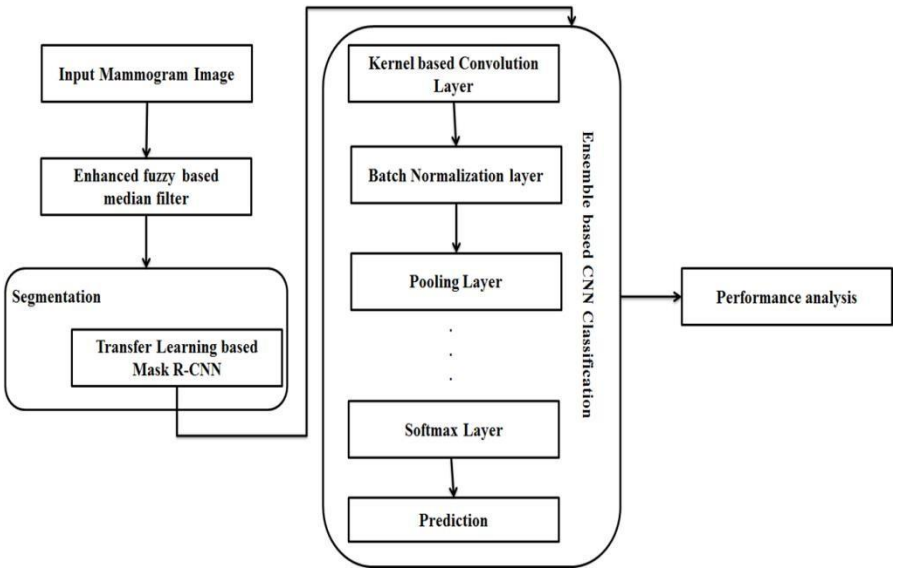

Figure 2: Overall Flow of Proposed Work

5.2.2 Segmentation with Transfer Learning based on Mask R-CNN

ROI is located using the segmentation process which is included in the pre-processing of mammogram images which gives clarity and better view analysis. Easy interpretation for adaptable for the mask R-CNN. Figure.3 shows the segmentation process based on the proposed system. Efficient architecture is considered for the medical segmentation and produces high quality mask for each

instance of objectives simultaneously. High precision is obtained by the proposed system with the detection of bounding box technique, key point detections, and instance segmentation. Figure 4 shows the framework of two-phase mask R-CNN.

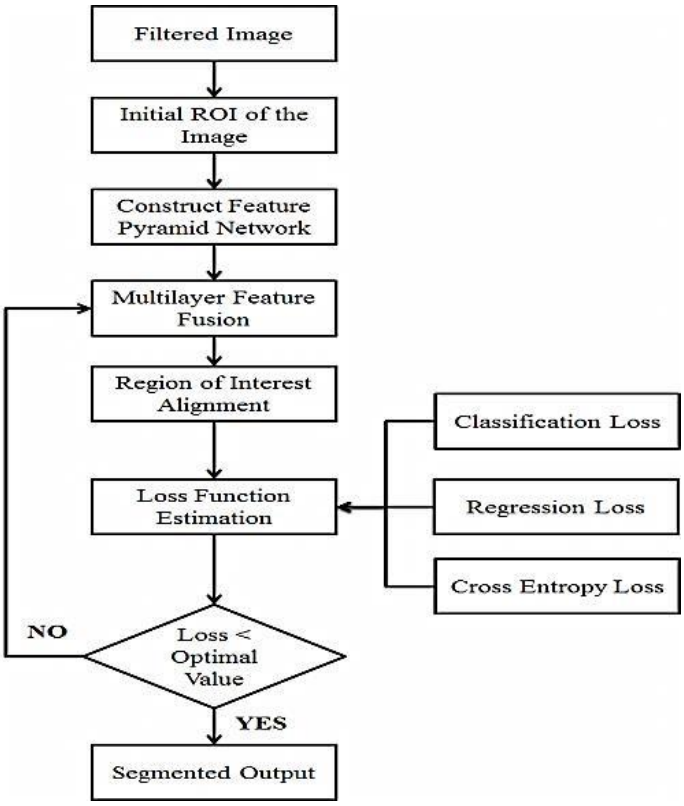

Figure 3: Segmentation with Transfer Learning based on Mask R-CNN

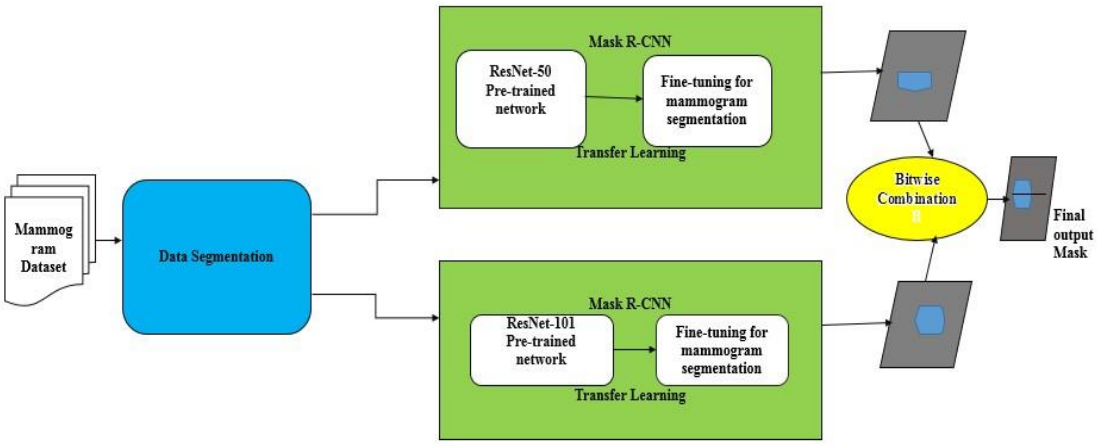

Figure 4: Deep Learning Techniques used for Breast Cancer Detection

Varied backbone-structure is prepared with the pre-trained model for providing convergence for training data to diverse solutions. ResNet50 is built with Mask R-CNN to obtain good results that used by the similar training data. Two assumed masks are combined based on bit-wise combinations. Overall, 90% of the data is used for training and 10% of dataset is used for testing for the proposed model based on the benign cases. Momentum and backbone model with stochastic gradient is paused and then updated with the proposed system. Momentum, learning rate, and weight decay of SGD must be fir from the range of
10 to 4, 0.9, and 10 to 3. When using 20 epochs, one hour of processing time is taken. Resuming the backbone model with respect to the modified whole network with SGD and momentum for full training phase.

5.3 Efficient Breast Cancer Detection using Novel Intensity Partitioning based Clustering

Breast cancer has become more common in women and requires early detection to reduce the mortality rate. In early days, doctors manually describe the suspected cancer affected area in the breast. Various studies have been conducted and many results have shown that manual segmentation takes more time. Cancer occurs in various stages. Only when the cancer is detected in the early stage there is a chance for preventing the patient's death rate. But, predicting breast cancer in the initial stage is a hard task for doctors as there is no visible symptoms. To resolve these various techniques have been introduced to detect and predict the type of breast cancer on-time. This also helps doctors to diagnose the disease quickly and prevent it before the patient's condition becomes critical. The techniques also classify the breast cancer as benign, malignant or healthy patients based on the results obtained. Various methods have been introduced to resolve the problems in detection of cancer. Those methods include decision Table, Naïve

Bayes, Lazy IBK, Ada Boost M1, Logistics Regression, Multilayer-perceptron, J-Rip, Multiclass Classifier, Random Tree, J48, Lazy K-star and random forest, Ehobi-LSTM, Lazy and tree algorithms.

5.3.1 Proposed System

Women who are susceptible to breast cancer must be given information regarding the significance of diagnosing breast cancer through analysis. They should also be assured that analysis is effective, simple and also safe. Accordingly, mass screening the breast cancer is the only confirmed technique that possess the ability to minimize the rate of stable death from this disease. Till true and primary prevention is introduced, it is vital to create mass screening highly effective, safe and economical. For this purpose, the study focused on various techniques based on image processing to detect the breast cancer which is further classified as malignant, benign or healthy person in accordance with the results attained from classification. Hence, through this study appropriate diagnosis can be made by medical practitioners.

Four processes are involved in this study where the proposed system uses mammogram image as input for detecting the breast cancer from DDSM dataset. At first, image pre-processing is performed. Subsequently, improvisation is included in segmentation and classification as these processes are more crucial in breast cancer detection where segmentation is performed using Novel Intensity Partitioning based Clustering algorithm- IPCA which is easy to execute, easy to converge the necessary segmented region as well as brighter region that has high-intensity is segmented efficiently. Then features are extracted from the segmented image. Finally classification is achieved using the Novel Multi-dimensional LSTM Cyclic Neural Network- MLSTM-CNN which preferred minimum weight initializations and LSTMs control the amount of innovative information being incorporated in the cell. After the implementation of the proposed methodology, the performance analysis is finally accomplished to determine the efficiency of the

proposed system in identifying the breast cancer. Thus the results revealed that the breast cancer detection is effectively achieved through the proposed system. The overall flow of the proposed system is given in Figure 5.

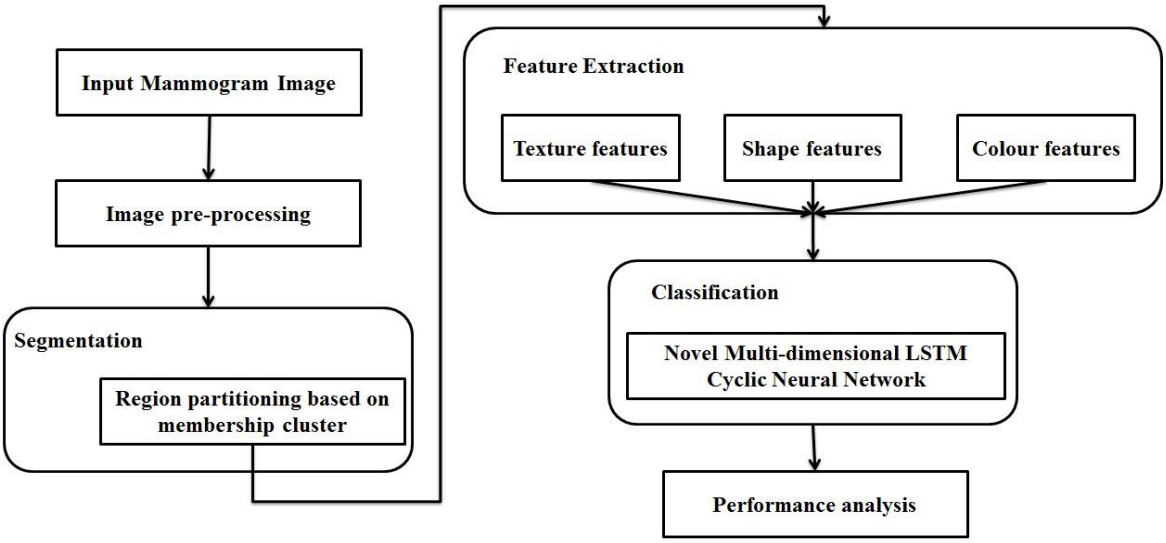

Figure 5: Overview of Proposed Workflow

5.4 Cloud Storage Based Diagnosis of Breast Cancer using Novel Transfer Learning with Multi-Layer Perceptron

Effective and efficient treatment can be considered for the early prediction of breast cancer. In this study, mammography or biopsy technique can be used for early detection of breast cancer. However, this study proved that biopsy is the efficient methodology for detecting the breast cancer. Digital image based on Fine Needle Aspiration (FNA) is pre-processed at the first stage. Feature are extracted from the images which used for the classification process. Feature attribute parameters are used for categorizing the features as benign or malignant. It is always a complex and challenging task when doing analysis and classification manually. Various researchers are shown interest in this particular area due to its automation requirement for detecting and classifying tumor-cells with cost effectiveness and accuracy. Therefore, some authors introduced feature reduction

and extraction based on PCA-LDA methodology that helps in minimizing the original feature space into a high extent. Effective accuracy is obtained when this minimized set is used for performing the training. For classification, ANNFIS classifier is utilized in this study. It is the combination of the ideas of fuzzy logic and neural network.

5.4.1 Proposed Methodology

Mammogram image is used as input for the proposed model. At first, pre-processing is done using median filter which is performed for removing the noise from the images. Novel Transfer Learning base Cancer Segmentation (TL-CAN-Seg) is used to perform segmentation and relevant features such as shape, color, and texture were extracted and it is stored in the cloud. At last, novel Multi-Layer Perceptron integrated with Levenberg Marquardt algorithm is used for performing classification by tuning the hyper parameters. The efficiency is confirmed by analyzing the proposed system performance. Figure 6 shows the overall workflow of the proposed architecture.

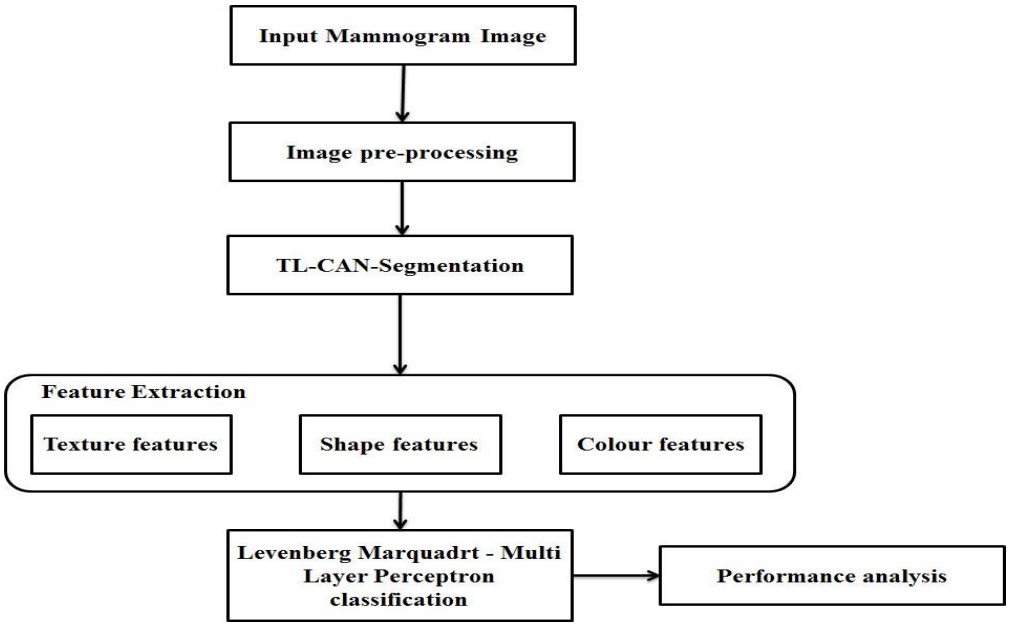

Figure 6: Overall Framework of Proposed System

After pre-processing step, the patches in the pixel of 512X512 and its labels were obtained for tuning the TL-CAN-Seg smoothly. The VGG network has personalized form with 16-layers networks. ImageNet dataset is used for training the model as it holds huge number of natural images. Based on the performance of segmentation, VGG network selection is encouraged. Furthermore, it holds up simple architecture when compared to ResNet and GoogleNet. The network is tuned by eliminating mean value of RGB from individual pixel patches. At first, segmentation is performed by converting the model into Fully Convolutional Network (FCN). Some of the sizes of blobs are smaller. For this reason, multiple Convolutional Transpose Layers (CTL) is utilized with minimized up-sampling strides, skipped-connections, and effective segmentation. The code from MATLAB for TL-CAN-Seg is changed. Figure 7 shows the consequent architecture.

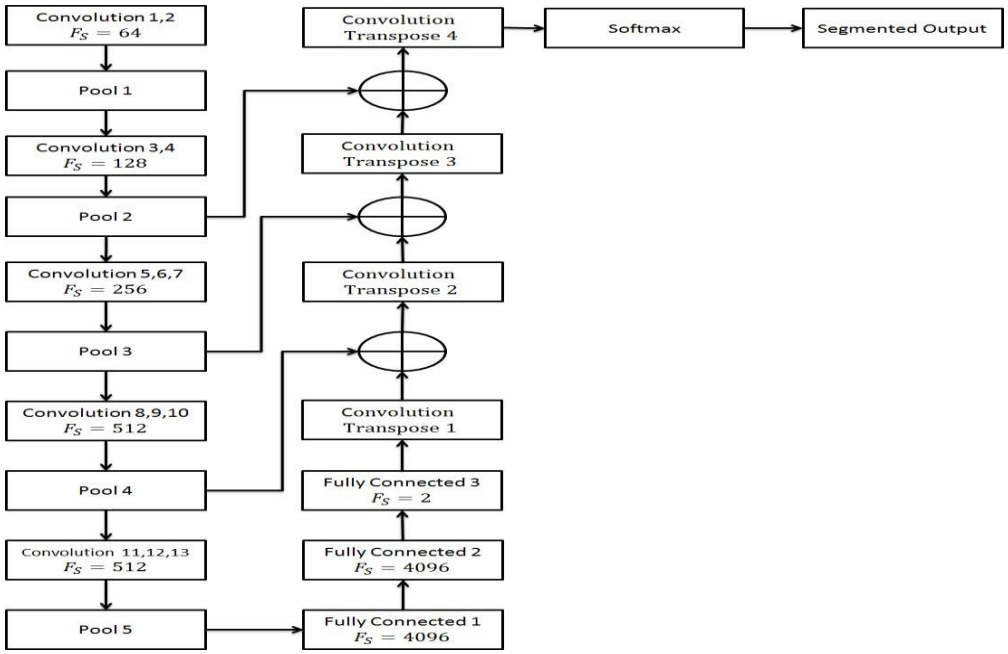

Figure 7: Segmentation using Novel TL-CAN-Seg.

6. THESIS ORGANIZATION

Chapter 1 – *"Introduction "presents* the causes and classification of cancer cells, breast cancer and about its types in mammograms. We discuss the need of Screening and Diagnosis in Mammogram Images. We also outline the benefits, risks and Limitation of Mammograms.

Chapter 2 *"Literature Review"* provides comprehensive survey of different existing techniques for early detection of breast cancer in mammogram images.

Chapter 3 *"Early Detection of Breast Cancer Using Hybrid of Series Network and Vgg-16 "proposed* decision based partial median filter for eliminating pepper and salt noises in mammogram images. Furthermore, we have extracted the segmented images using BAT-SURF technique and then used Gradient descent decision tree classifier to detect the breast cancer.

Chapter 4 *"Detecting Breast Cancer Using Novel Mask R-Cnn Techniques"* used the using median filter based enhanced fuzzy filter to remove different types of noises and present mask R-CNN technique to segment the mammogram images of breast cancer and classify the malignant and benign using ensemble CNN method.

Chapter 5 "*Efficient Breast Cancer Detection Using Novel Intensity Partitioning Based Clustering Algorithm and Multi-Dimensional LSTM Cyclic Neural Network"* proposed Novel Multi-dimensional LSTM Cyclic Neural Network (MLSTM-CNN) for the classification of breast cancer mammogram images in which we used Intensity Partitioning based Clustering Algorithm (IPCA) for segmentation process.

Chapter 6 *"Cloud Storage Based Diagnosis of Breast Cancer Using Novel Transfer Learning with Multi-Layer Perceptron* "discussed the proposed Transfer Learning based Cancer Segmentation (TL-CAN-Seg) method is proposed to

segment the cancer affected areas. Also, MLP (Multi-layer perceptron) with tuned Levenberg Marquadrt algorithm (LM) is proposed to classify the breast cancer images efficiently.

Chapter 7 *"Conclusion and Future work"* summarizes the key results, conclusions of this thesis and outlines the future scope of work.

7. REFERENCES

1. Mahmood, B., Muhammad, B., Abbas, R., Rabia, A., Arun, K., Hamed, H., George, Z.K., Nano diagnosis and Nano treatment of colorectal cancer: An overview., *Journal of Nanoparticle Research*, **23**(1)(2021),1-25.

2. Johnson, C.A., James, D., Marzan, A., Armaos, M., Cervical cancer: an overview of pathophysiology and management. , *Seminars in oncology nursing*, **35**(2) (2019), 166-174.

3. Sharma, G.N., Dave, R., Sanadya, J., Sharma, P., Sharma, K.K., Various types and management of breast cancer: an overview, *Journal of advanced pharmaceutical technology & research*, **1**(2) (2010), 109-126.

4. Rangarajan, B., Shet, T., Wadasadawala, T., Nair, N.S., Sairam, R.M., Hingmire, S.S., Bajpai, J., Breast cancer: An overview of published Indian data. , *South Asian journal of cancer*, **5**(3) (2016), 86-92.

5. Elmore, J.G., Armstrong, K., Lehman, C.D., Fletcher, S.W., Screening for breast cancer. , *Jama*, **293**(10) (2005), 1245-1256.

6. Sun, Y.S., Zhao, Z., Yang, Z.N., Xu, F., Lu, H.J., Zhu, Z.Y., Shi ,W., Jiang, J., Yao, P.P., Zhu, H.P., Risk factors and preventions of breast cancer. , *International journal of biological sciences*, **13**(11) (2017), 1387.

7. Acharya, U.R., Ng, E.Y., Tan, J.H., Sree, S.V., Thermography based breast cancer detection using texture features and support vector machine., *Journal of medical systems* , **36**(3) (2012), 1503-1510.

8. Saha, M., Chakraborty, C., Racoceanu, D., Efficient deep learning model for mitosis detection using breast histopathology images., *Computerized Medical Imaging and Graphics* , **64** (2018), 29-40.

9. Kooi, T., Litjens, G., van Ginneken, B., Gubern-Merida, A., Sanchez, C.I., Mann, R., den Heeten, A., Karssemeijer, N., Large scale deep learning for computer aided detection of mammographic lesions., *Medical image analysis* , **35** (2017) , 303-312.

10. Radovic , M., Djokovic, M., Peulic, A., Filipovic, N., Application of datamining algorithms for mammogram classification. *IEEE International Conference on Bioinformatics and Bioengineering.* , (2013).

11. Dheeba, J., Singh,N.A., Selvi,T., Computer-aided detection of breast cancer on mammograms: A swarm intelligence optimized wavelet neural network approach., *Journal of biomedical informatics* , **49** (2014) , 45-52.

12. El-Dahshan, El-Sayed A., Mohsen, Heba, M., Salem, Abdel-Badeeh, M.,Computer-aided diagnosis of human brain tumor through MRI: A survey and a new algorithm., *Expert systems with Applications* , **41**(11) (2014), 5526-5545.

13. Parascandolo, P., Cesario, L., Vosilla , L., Viano G.,, Computer aided diagnosis: state-of-the-art and application to musculoskeletal diseases., *3D multiscale physiological human*., (2014) 277-296.

8. LIST OF PUBLICATIONS

1. **Gul Shaira Banu Jahangeer**, and **T. Dhiliphan Rajkumar**. , Early detection of breast cancer using hybrid of series network and VGG-16. , *Multimedia Tools and Applications*, **80** (5) (2021), 7853-7886. **(SCI-IF: 2.757) [Published].**

2. **Gul Shaira Banu Jahangeer**, and **T. Dhiliphan Rajkumar**. , Detecting breast cancer using novel mask R-CNN techniques, *Expert Systems*, *https://doi.org/10.1111/exsy.12954*, **e12954** (2022). **(SCI-IF: 2.587) [Published].**

3. **Gul Shaira Banu Jahangeer**, and **T. Dhiliphan Rajkumar**., Efficient breast cancer detection using novel intensity partitioning based clustering algorithm and multi-dimensional lstm cyclic neural network. , *International Journal of Medical Engineering and Informatics, Inderscience, 10.1504/IJMEI.2021.10043507,*(2022). **(SCOPUS)[Forthcoming Article].**

4. **Gul Shaira Banu Jahangeer**, and **T. Dhiliphan Rajkumar**. , Cloud storage based diagnosis of breast cancer using novel transfer learning with multi-layer perceptron, *International Journal of System Assurance Engineering and Management, Springer*, (2022). **[ESCI-SCOPUS] [Published]**